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Statistical Analysis of Parameter Prediction of Various Military Fuel Samples Utilizing Their Gas Liquid Chromatograms

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There is a research effort that envisions having a vehicle mounted petroleum analysis system that could travel close to the frontlines and would provide rapid test results. This system would quicken results feedback time and increase the scope of analyses by using new technologies that could predict several fuel properties and parameters. One approach under consideration for use in this system is Gas Liquid-Phase Chromatography (GLC).

Previous results using GLC data from an oven profile that resulted in a sixty-minute analysis time resulted in a 100% correct classification as to fuel type and predictions of the 10%, 50%, and 90%, and final boiling point distillation temperatures; and the densities of the samples with relatively low errors of prediction. To reduce the analysis test time, oven profiles were developed to give a twelve-minute GLC analysis time and the statistical analysis of the two oven profiles were compared to determine if the shorter test time would yield comparable results.

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Preface

This endeavor was initiated to determine the feasibility of fuel analysis using Gas Liquid-Phase Chromatography (GLC). The GLC is one of several analytical techniques that is under consideration for use in a proposed petroleum product analyzing system.

SECTION 1

INTRODUCTION

An earlier report detailed the use of GLC as an effective method for fuel type classification and parameter prediction.(1)[1] In that study sixty-four fuel samples were analyzed using a single GLC column and oven parameter profile pair. The effectiveness of the generated models at fuel type classification and fuel parameter prediction were established by statistical analysis of the classification and prediction errors.

To optimize the prediction and oven profile parameter pairs, seventeen samples were repetitively analysis using seven (7) different GLC columns and oven parameters.(2) From this study the DB-1/HP-1 columns appeared to be the best columns for the current analysis as was evident by the minimum prediction errors with these columns. In an effort to reduce the analysis time, oven profiles were established to give an analysis time of twelve minutes. The prediction errors of the model generated using the new oven profiles were compared to the results from the sixty-minute data analysis.

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[1] Superscript numbers in parenthesis refer to references at the end of the report.

SECTION 2 TEST PARAMETERS

FUEL SAMPLE SET

To conduct this study, sixty-seven (67) fuel samples were used of which fifteen were Jet A-1 or Jet A conforming to ASTM D1655, "Standard Specification for Aviation Turbine Fuels"[3], twelve were Grade JP-4 and nine Grade JP-5 fuels conforming to Military Specification MIL-T-5624P, "Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8 ST"[4]; twelve were AVGAS conforming to ASTM D 910, "Standard Specification for Aviation Gasolines"[5]; nine were JP-8 conforming to Military Specification MIL-T-83133, "Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-35"[6]; seven were MOGAS conforming to Military Specification MIL-G-3056F, "Gasoline, Automotive, Combat"[7]; and, three Grade DF-2 fuels conforming to Federal Specification VV-F-800D, "Fuel Oil, Diesel"[8].

The fuel samples used in the study were obtained from three sources: the Fuels Branch, Fuels and Lubricant Division, Wright-Patterson Air Force Base (WPAFB), OH; Directorate of Aerospace Fuels, Detachment 13 (the Kelly AFB contingent at WPAFB); and the US Army TARDEC Fuels and Lubricants Research Facility (TFLRF) at SwRI, San Antonio, TX (formerly the Belvoir Fuels and Lubricants Research Facility (BFLRF)). A list of the fuel samples used in the study is given in APPENDIX A and the specification test data for the fuel samples is given in the initial report [1].

GLC Column and Oven Parameter Pairs

As performed in previous studies[1][2], the fuel samples' GLC chromatograms were reduced from as many as a few hundred peaks to as few as fifteen peaks. This reduction was facilitated by utilizing a peak-lumping feature in the chromatographic collection software. The peaks were lumped by combining all of the peaks in a given time interval into a single peak. The retention times of the alkane standards and the time intervals for the chosen regions for both the sixty-minute and the twelve-minute analyses are given in Tables 1 and 2 respectively.

CONDITIONS OF FID Sixty-Minute & HP-1

The HP5890 GC was set to an initial temperature of 40°C, with a hold time for 5.0 minutes, a program ramp 6.0°C per minute, to a final temperature of 250°C, with a hold time of 20.0 minutes. A Flame Ionization Detector (FID) was used with a 30 meter megabore column, 0.53 cm inside diameter with a 2.65 μm film coat of methyl silicone (HP-1). The carrier gas was helium with a flow rate of 8.6 mL per minute. The time constraints for the segmented regions and retention times for the alkane standards are given in table 1:

TABLE 1: Time Constraints For FID Sixty-Minute & HP-1 Analysis

Region	n-Alkane	Retention Time	Time Boundaries
1	C5	1.589 min	0.00 - 2.27 min
2	C6	2.937 min	2.27 - 4.62 min
3	C7	6.298 min	4.62 - 8.33 min
4	C8	10.368 min	8.33 - 12.24 min
5	C9	14.117 min	12.24 - 15.77 min
6	C10	17.413 min	15.77 - 18.95 min
7	C11	20.475 min	18.95 - 21.87 min
8	C12	23.261 min	21.87 - 24.55 min
9	C13	25.828 min	24.55 - 27.07 min
10	C14	28.315 min	27.07 - 29.37 min
11	C15	30.412 min	29.37 - 31.54 min
12	C16	32.663 min	31.54 - 33.66 min
13	C17	34.647 min	33.66 - 35.64 min
14	C18	36.645 min	35.64 - 37.50 min
15	C19	38.363 min	37.50 - 39.26 min
16	C20	40.152 min	39.26 - 41.44 min
17	C21	---------	41.44 - 44.02 min
18	C22	---------	44.02 - 46.61 min
19	C23	---------	46.61 - 49.19 min
20	C24	50.476 min	49.19 - 60.00 min

CONDITIONS OF FID Twelve-Minute & HP-1

The HP5890 GC was set to initial temperature of 40°C, with a hold time for 0.0 minutes, a program ramp 25.0°C per minute, to a final temperature of 250°C, with a hold time of 7.0 minutes. A FID was used with a 10 meter megabore column, 0.53 cm inside diameter with a 2.65 μm film coat of methyl silicone (HP-1). The carrier gas was helium with a flow rate of 9.6 mL per minute. The time constraints for the segmented regions and the retention times for the alkane standards is given in table 2.

TABLE 2: Time Constraints For FID Twelve-Minute & HP-1 Analysis

Region	n-Alkane	Retention Time	Time Boundaries
1	C5	0.591 min	0.00 - 0.75 min
2	C6	0.907 min	0.75 - 1.16 min
3	C7	1.419 min	1.16 - 1.74 min
4	C8	2.068 min	1.74 - 2.42 min
5	C9	2.773 min	2.42 - 3.12 min
6	C10	3.468 min	3.12 - 3.80 min
7	C11	4.136 min	3.80 - 4.45 min
8	C12	4.764 min	4.45 - 5.06 min
9	C13	5.355 min	5.06 - 5.63 min
10	C14	5.912 min	5.63 - 6.17 min
11	C15	6.434 min	6.17 - 6.68 min
12	C16	6.931 min	6.68 - 7.16 min
13	C17	7.397 min	7.16 - 7.63 min
14	C18	7.857 min	7.63 - 8.07 min
15	C19	8.284 min	8.07 - 8.49 min
16	C20	8.693 min	8.49 - 9.04 min
17	C21	---------	9.04 - 9.74 min
18	C22	---------	9.74 - 10.44 min
19	C23	---------	10.44 - 11.14 min
20	C24	11.489 min	11.14 - 14.98 min

SECTION 3 TEST RESULTS FOR 60-MINUTE ANALYSIS

Classification Prediction

From the initial analysis, samples # 339 (MO-GAS), 93-F-591 (JP-4) and 93-F-643 (AVGAS) were identified as statistical outliers from the other samples. These determinations were based on a Hierarchical Cluster Analysis (HCA) which grouped the samples based on the similarity of their GLC data. With a HCA analysis, the three outliers were placed into grouping outside of the other samples of the identical type.

Once the outliers were removed HCA analysis resulted in five groups consisting of AVGAS, JP-4, MO-GAS, DF-2, and a combined group of JP-5, JP-8, and JET A. There were no misclassifications and all of the samples were assigned to their proper class. The class assignments from the KNN model for each of the fuel samples are given in Appendix B.

To test the rigors of the classification model, seventeen randomly selected samples were removed from the data set and a KNN model was made using the remaining data points. The seventeen samples included eight JP-8 group samples, three JP-4, three AVGAS, two MOGAS, and one DF-2. The generated classification model was then applied to the removed samples and resulted in 100 % correct class determination for the samples in the removed set. A list of the removed samples and their class assignments are given in Appendix C.

PARAMETER PREDICTION

The GLC data was also used to develop models to predict the 10 %, 50 %, 90 %, and final boiling point temperatures; the density; and the viscosity at 40° and 100°C. Using the results of the predictions, the average error and average % error were calculated. Table 3 is a listing of the average error and average % error for the generated prediction models.

TABLE 3: Statistical Analysis of Parameter Predictions

PARAMETER	JP-8 SEPARATED MODEL[1]		TOTAL MODEL[2]	
	ERROR[3]	% ERROR[4]	ERROR	% ERROR
10% BP TEMP (°K)	5.14	1.13	10.2	2.57
50% BP TEMP (°K)	3.61	0.74	7.86	1.80
90% BP TEMP (°K)	6.39	1.23	11.7	2.44
FINAL BP TEMP (°K)	9.68	1.77	16.9	3.29
DENSITY (g/mL)	0.00440	0.546	0.00859	1.10
VIS @ 40°C (cSt)	0.191	11.7	0.235	19.1
VIS @ 100°C (cSt)	0.0973	13.5	0.0575	10.4

1. The JP-8 separated model was a correlation model that was developed from samples of the JP-8 group.
2. The total model was a correlation model that was developed from all of the samples.
3. The average error = $\frac{\sum_{1}^{N}|V_{ci}-V_{mi}|}{N}$ where V_{ci} and V_{mi} are the calculated and the measured value of the Nth parameter.
4. The average % error = $\frac{(average\ error)\times 100}{average\ V_{mi}}$

To test the rigor of the models at predicting parameters of samples that weren't included in the correlation models, five data sets were removed from the correlation models generation sets and Partial Least Squares (PLS) regression method were used to predict the listed parameters. Tables 4 thru 10 are listing of the predicted values and errors of prediction for the five samples. Plots of the predicted versus the measured parameters for all samples with all samples included in the correlation models generation sets are given in Appendix D.

TABLE 4: 10 % Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	449	439	2.23	443	1.34
92-POSF-2934	424	439	3.53	440	3.77
92-POSF-2747	458	459	0.22	468	2.18
93-F-304	475	456	4.00	449	5.47
93-F-668	442	458	3.62	456	3.17

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

TABLE 5. 50% Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	472	475	0.63	468	0.85
92-POSF-2934	475	478	0.63	465	2.11
92-POSF-2747	466	468	0.43	481	3.22
93-F-304	505	485	3.96	483	4.36
93-F-668	484	486	0.41	490	1.24

1. The actual value point is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all samples.

TABLE 6. 90% Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	504	516	2.38	511	1.39
92-POSF-2934	522	516	1.15	517	0.96
92-POSF-2747	484	481	0.62	483	0.21
93-F-304	548	533	2.74	524	4.38
93-F-668	533	536	0.56	523	1.88

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 7. Final Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	523	535	2.29	537	2.68
92-POSF-2934	543	527	2.95	543	0.00
92-POSF-2747	509	509	0.00	515	1.18
93-F-304	566	565	0.18	551	2.65
93-F-668	600	589	1.83	553	7.83

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 8. Density

SAMPLE NUMBER	ACTUAL VALUE[1] (g/mL)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (g/mL)	% ERROR	PREDICTED (g/mL)	% ERROR
92-POSF-2959	792	799	0.90	797	0.63
92-POSF-2934	808	796	1.44	796	1.18
92-POSF-2747	807	804	0.36	790	2.11
92-F-304	812	807	0.62	804	0.99
92-F-668	823	810	1.58	813	1.22

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 9. Viscosity at 40°C

SAMPLE NUMBER	ACTUAL VALUE[1] (cSt)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (cSt)	% ERROR	PREDICTED (cSt)	% ERROR
92-POSF-2959	1.442	1.510	4.716	1.432	0.694
92-POSF-2934	1.545	1.498	3.042	1.591	2.977
92-POSF-2747	1.530	1.526	0.261	1.244	18.69
93-F-304	1.769	1.715	3.053	1.926	8.875
93-F-668	1.897	1.725	9.067	1.878	1.002

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 10. Viscosity at 100°C

SAMPLE NUMBER	ACTUAL VALUE[1] (cST)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (cSt)	% ERROR	PREDICTED (cSt)	% ERROR
92-POSF-2959	0.7922	0.7914	0.101	0.7411	6.450
92-POSF-2934	0.7586	0.7420	2.188	0.7296	3.823
92-POSF-2747	0.7464	0.6540	12.38	0.7795	4.435
93-F-304	0.8248	0.9122	10.60	0.8289	0.497
93-F-668	0.8169	0.9346	14.41	0.9051	11.08

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

SECTION 4 TEST RESULTS FOR TWELVE-MINUTE ANALYSIS

CLASSIFICATION PREDICTION

From the initial analysis, sample # 93-F-643 (AVGAS) was identified as statistical outlier from the other samples. This determination was based on a Hierarchical Cluster Analysis (HCA) which grouped the samples based on the similarity of their GLC data. With a HCA analysis, sample # 93-F-643 was placed into a group outside the other samples of identical type.

Once the outlier was removed, HCA analysis resulted in four groups consisting of AVGAS, DF-2, a combined group of JP-4 and MOGAS, and a combined group of JP-5, JP-8, and JET A. Three samples were misclassifications with all of the other samples being to their proper class. It should be noted that for each samples misclassified, a duplicate GLC analysis was conducted and was properly classified. The class assignments from the KNN model for each of the fuel samples are given in Appendix B.

To test the rigors of the classification model, seventeen randomly selected samples were removed from the data set and a KNN model was made using the remaining data points. The seventeen samples included eight JP-8 group samples, five JP-4 group samples, three AVGAS, and one DF-2. The generated classification model was then applied to the removed samples and resulted in all of the fuel samples being correctly classified. A list of the removed samples and their class assignments are given in Appendix C.

PARAMETER PREDICTION

The GLC data was also used to develop models to predict the 10 %, 50 %, 90 %, and final boiling point temperatures; the density; and the viscosity at 40° and 100°C. Using the results of the predictions, the errors were calculated. Table 11 is a listing of the average error and average % error for the generated models.

TABLE 11: Statistical Analysis of Parameter Predictions

PARAMETER	JP-8 SEPARATED MODEL[1]		TOTAL MODEL[2]	
	ERROR[3]	% ERROR[4]	ERROR	% ERROR
10% BP TEMP (°K)	6.19	1.37	12.0	3.23
50% BP TEMP (°K)	5.33	1.10	9.82	2.44
90% BP TEMP (°K)	9.47	1.85	14.9	3.23
FINAL BP TEMP (°K)	13.3	2.42	20.3	4.01
DENSITY (g/mL)	0.00361	0.45	0.00596	0.76
VIS @ 40°C (cSt)	0.198	11.8	0.218	17.1
VIS @ 100°C (cSt)	0.0512	7.55	0.04782	7.34

1. The JP-8 separated model was a correlation model that was developed from samples of the JP-8 group.
2. The total model was a correlation model that was developed from all of the samples.

3. The average error $= \dfrac{\sum_{1}^{N} |V_{ci} - V_{mi}|}{N}$ where V_{ci} and V_{mi} are the calculated and the measured value of the Nth parameter.

4. The average % error $= \dfrac{(\textit{average error}) \times 100}{\textit{average } V_{mi}}$

To test the rigor of the models at predicting parameters of samples that weren't included in the correlation model, five data sets were removed from the correlation models and Partial Least Squares (PLS) regression method were used to predict the listed parameters. Tables 12 thru 18 are listing of the predicted values and errors of prediction for the five samples. Plots of the predicted versus the measured parameters for all samples with all samples included in the correlation model are given in Appendix D.

TABLE 12: 10 % Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	449	450	0.22	435	3.12
92-POSF-2934	424	451	6.37	434	2.36
92-POSF-2747	458	444	3.06	425	7.21
93-F-304	475	456	4.00	449	5.47
93-F-668	442	451	2.04	456	3.17

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

TABLE 13. 50% Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	472	482	2.12	475	0.64
92-POSF-2934	475	481	1.26	471	0.84
92-POSF-2747	466	488	4.72	511	9.66
93-F-304	505	484	4.16	487	3.56
93-F-668	484	485	0.21	485	0.21

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

TABLE 14. 90% Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	504	521	3.37	532	5.56
92-POSF-2934	522	521	0.19	531	1.72
92-POSF-2747	484	524	8.26	551	13.8
93-F-304	548	520	5.11	524	4.38
93-F-668	533	521	2.25	530	0.56

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 15. Final Boiling Point Temperature

SAMPLE NUMBER	ACTUAL VALUE[1] (°K)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (°K)	% ERROR	PREDICTED (°K)	% ERROR
92-POSF-2959	523	545	2.29	567	8.41
92-POSF-2934	543	542	0.20	566	4.24
92-POSF-2747	509	562	10.4	593	16.5
93-F-304	566	536	5.30	547	3.36
93-F-668	600	552	8.00	563	6.17

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3.The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 16. Density

SAMPLE NUMBER	ACTUAL VALUE[1] (g/mL)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (g/mL)	% ERROR	PREDICTED (g/mL)	% ERROR
92-POSF-2959	792	806	1.77	805	1.64
92-POSF-2934	808	806	0.25	805	0.37
92-POSF-2747	807	809	0.37	813	0.74
92-F-304	812	806	0.74	807	0.62
92-F-668	823	807	1.94	808	1.82

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 17. Viscosity at 40°C

SAMPLE NUMBER	ACTUAL VALUE[1] (cSt)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (cSt)	% ERROR	PREDICTED (cSt)	% ERROR
92-POSF-2959	1.442	1.703	18.10	1.815	25.87
92-POSF-2934	1.545	1.716	11.07	1.792	15.99
92-POSF-2747	1.530	1.535	0.327	1.518	0.784
93-F-304	1.769	1.780	0.622	1.679	5.088
93-F-668	1.897	1.702	10.28	1.674	11.76

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

Table 18. Viscosity at 100°C

SAMPLE NUMBER	ACTUAL VALUE[1] (cSt)	GROUP 1 MODEL[2]		TOTAL MODEL[3]	
		PREDICTED (cSt)	% ERROR	PREDICTED (cSt)	% ERROR
92-POSF-2959	0.7922	0.7584	4.267	0.8024	1.288
92-POSF-2934	0.7586	0.7616	0.395	0.7932	4.561
92-POSF-2747	0.7464	0.7187	3.711	0.7237	3.041
93-F-304	0.8248	0.8075	2.0975	0.8156	1.115
93-F-668	0.8169	0.7802	4.493	0.7775	4.823

1. The actual value is the parameter's measured value.
2. The Group 1 Model is the parameter's predicted value using a model that was developed using data point from the JP-8 group samples.
3. The Total Model is the parameter's predicted value using a model that was developed using data points from all of the samples.

SECTION V
CONCLUSION

For both the twelve-minute and the sixty-minute analysis, two set of prediction were determined. One set of prediction data consisted of using models that were generated from JET A, JET A-1, JP-5 and JP-8 (or collectively termed Group 1 samples) samples and the second set of prediction data consisted of using models that were generated from all sixty-seven fuel samples.

With both the twelve-minute and the sixty-minute prediction set, the average percent errors of the predicted versus the actual parameter values are relatively small (less than 2 %). Also, the difference between the average percent errors of model developed from GROUP 1 samples and the models developed from all sixty-seven data sets were relative small (less than 2 %) for the 10 %, 50 %, 90 %, and final boiling point temperature; and the density. The low errors for both the sixty-minute and twelve-minute analyses suggest that both model sets are useful for the prediction of the above parameters.

Although the errors for the twelve-minute analyses are slightly higher than the errors of the sixty-minute analyses, the reduction in sample analysis time more than makes up for the slightly higher errors. This shows that twelve-minute analysis time may be used to decrease sample test time and to increase sample through put.

For the predictions of the viscosities at 40° and 100°C for both analyses, the average percent error of the predicted versus the actual parameter values are relatively large (more than 10 %) which shows that these parameters are not good candidates for prediction using the GLC data.

Future work will involve studing the effects of column wall thickness on the GLC analysis, and inclusion of additional fuel samples and parameters for prediction.

References

1. Minus, D. K., "Fuel-Type Classification and Parameters Prediction by Gas Liquid Chromatography Analysis, TARDEC Technical Report # 13641, February, 1995, U.S. Army Tank-Automotive Command Research, Development and Engineering Center, Warren, Michigan 48397-5000.

2. Minus, D. K., "Fuel Classification and Parameter Prediction Using GLC Analysis", Mobility Technology Center - Belvoir Letter Report # 96-2, October, 1995, U.S. Army Tank-Automotive Command Research, Development and Engineering Center, Warren, Michigan 48397-5000.

3. ASTM D1655 "Standard Specification for Aviation Turbine Fuels." American Society For Testing And Materials, 1916 Race Street, Philadelphia, PA 19103.

4. Military Specification MIL-T-5624P, "Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8ST." September 1992.

5. ASTM D910 "Standard Specification for Aviation Gasolines." American Society For Testing And Materials, 1916 Race Street, Philadelphia, PA 19103.

6. Military Specification MIL-T-83133D, "Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-35." January 1992.

7. Military Specification MIL-G-3056F, "Gasoline, Automotive, Combat." November 1991.

8. Federal Specification VV-F-800D, "Fuel Oil, Diesel." October 1987.

APPENDIX A

List of Fuel Samples

TABLE 19. List of Fuel Samples

SAMPLE NUMBER	SAMPLE ORIGIN	FUEL TYPE	TEST DATA
93-POSF-2959	WPAFB BLDG 490	JET A	YES
92-POSF-2928	WPAFB BLDG 490	JET A	YES
92-POSF-2926	WPAFB BLDG 490	JET A	YES
93-POSF-2747	WPAFB BLDG 490	JET A	YES
92-POSF-2930	WPAFB BLDG 490	JET A	YES
91-POSF-2827	WPAFB BLDG 490	JET A	YES
92-POSF-2922	WPAFB BLDG 490	JET A	YES
93-F-173	WPAFB KELLY AFB DET	JET A	YES
93-F-142	WPAFB KELLY AFB DET	JET A	YES
93-F-304	WPAFB KELLY AFB DET	JET A	YES
93-F-280	WPAFB KELLY AFB DET	JET A	YES
93-F-560	WPAFB KELLY AFB DET	JET A	YES
93-F-665	WPAFB KELLY AFB DET	JET A	YES
93-F-444	WPAFB KELLY AFB DET	JET A	YES
92-POSF-2931	WPAFB BLDG 490	JET A-1	YES
92-POSF-2936	WPAFB BLDG 490	JP-8	YES
92-POSF-2934	WPAFB BLDG 490	JP-8	YES
91-POSF-2817	WPAFB BLDG 490	JP-5	YES
93-F-0284	WPAFB KELLY AFB DET	JP-5	YES
93-F-311	WPAFB KELLY AFB DET	JP-5	YES
93-F-312	WPAFB KELLY AFB DET	JP-5	YES
93-F-310	WPAFB KELLY AFB DET	JP-5	YES
93-F-313	WPAFB KELLY AFB DET	JP-5	YES
93-F-374	WPAFB KELLY AFB DET	JP-5	YES
93-F-668	WPAFB KELLY AFB DET	JP-5	YES
93-L-100	WPAFB KELLY AFB DET	DF-2	YES
93-F-625	WPAFB KELLY AFB DET	JP-4	YES
93-F-653	WPAFB KELLY AFB DET	JP-4	YES
93-F-586	WPAFB KELLY AFB DET	JP-4	YES
93-F-640	WPAFB KELLY AFB DET	JP-4	YES
93-F-591	WPAFB KELLY AFB DET	JP-4	YES
93-F-152	WPAFB KELLY AFB DET	JP-4	YES
93-F-412	WPAFB KELLY AFB DET	JP-4	YES
93-F-347	WPAFB KELLY AFB DET	JP-4	YES
93-F-402	WPAFB KELLY AFB DET	JP-4	YES
93-F-233	WPAFB KELLY AFB DET	JP-4	YES
93-F-201	WPAFB KELLY AFB DET	AVGAS	YES
93-F-295	WPAFB KELLY AFB DET	AVGAS	YES
93-F-289	WPAFB KELLY AFB DET	AVGAS	YES
93-F-290	WPAFB KELLY AFB DET	AVGAS	YES
93-F-279	WPAFB KELLY AFB DET	AVGAS	YES
93-F-644	WPAFB KELLY AFB DET	AVGAS	YES
93-F-643	WPAFB KELLY AFB DET	AVGAS	YES
93-F-609	WPAFB KELLY AFB DET	AVGAS	YES
93-F-539	WPAFB KELLY AFB DET	AVGAS	YES
93-F-610	WPAFB KELLY AFB DET	AVGAS	YES
93-F-338	WPAFB KELLY AFB DET	AVGAS	YES
93-F-551	WPAFB KELLY AFB DET	AVGAS	YES
93-F-326	WPAFB KELLY AFB DET	MOGAS	YES
93-F-307	WPAFB KELLY AFB DET	MOGAS	YES
93-F-339	WPAFB KELLY AFB DET	MOGAS	YES
93-F-306	WPAFB KELLY AFB DET	MOGAS	YES
93-F-464	WPAFB KELLY AFB DET	MOGAS	YES
93-F-638	WPAFB KELLY AFB DET	MOGAS	YES
93-F-449	WPAFB KELLY AFB DET	MOGAS	YES

APPENDIX B

Classification Prediction

Table 20: Result of Classification Analysis Using 12 & 60 min data.

SAMPLE #	FUEL TYPE	Classification of samples using the 60 min data analysis	Classification of samples using the 12 min data analysis
93-POSF-2959	JET A	GROUP 1[1]	GROUP 1
92-POSF-2928	JET A	GROUP 1	GROUP 1
92-POSF-2926	JET A	GROUP 1	GROUP 1
93-POSF-2747	JET A	GROUP 1	GROUP 1
92-POSF-2930	JET A	GROUP 1	GROUP 1
91-POSF-2827	JET A	GROUP 1	GROUP 1
92-POSF-2922	JET A	GROUP 1	GROUP 1
93-F-173	JET A	GROUP 1	GROUP 1
93-F-142	JET A	GROUP 1	GROUP 1
93-F-304	JET A	GROUP 1	GROUP 1
93-F-280	JET A	GROUP 1	GROUP 1
93-F-665	JET A	GROUP 1	GROUP 1
93-F-444	JET A	GROUP 1	GROUP 1
93-F-560	JET A	GROUP 1	GROUP 1
92-POSF-2931	JET A-1	GROUP 1	GROUP 1
AL-19850-F	JP-8	GROUP 1	GROUP 1
AL-20123-F	JP-8	GROUP 1	GROUP 1
AL-20336-F	JP-8	GROUP 1	GROUP 1
AL-19903-F	JP-8	GROUP 1	GROUP 1
93-F-351	JP-8	GROUP 1	GROUP 1
92-POSF-2934	JP-8	GROUP 1	GROUP 1
AL-20335-F	JP-8	GROUP 1	GROUP 1
AL-20011-F	JP-8	GROUP 1	GROUP 1
92-POSF-2936	JP-8	GROUP 1	GROUP 1
93-POSF-2963	JP-5	GROUP 1	GROUP 1
91-POSF-2817	JP-5	GROUP 1	GROUP 1
93-F-284	JP-5	GROUP 1	GROUP 1
93-F-311	JP-5	GROUP 1	GROUP 1

[1] GROUP 1 consists of JP-5, JP-8, JET A, and JET A-1 samples.

TABLE 20: Result of Classification Analysis Using 12 & 60 min data (continued).

SAMPLE#	FUEL TYPE	Classification of samples using the 60 min data analysis	Classification of samples using the 12 min data analysis
93-F-312	JP-5	GROUP 1	GROUP 1
93-F-310	JP-5	GROUP 1	GROUP 1
93-F-313	JP-5	GROUP 1	GROUP 1
93-F-374	JP-5	GROUP 1	GROUP 1
93-F-668	JP-5	GROUP 1	GROUP 1
93-F-201	AVGAS	AVGAS	AVGAS
93-F-295	AVGAS	AVGAS	AVGAS
93-F-289	AVGAS	AVGAS	AVGAS
93-F-290	AVGAS	AVGAS	AVGAS
93-F-279	AVGAS	AVGAS	AVGAS
93-F-643	AVGAS	AVGAS	AVGAS
93-F-551	AVGAS	AVGAS	AVGAS
93-F-644	AVGAS	AVGAS	AVGAS
93-F-338	AVGAS	AVGAS	AVGAS
93-F-609	AVGAS	AVGAS	AVGAS
93-F-610	AVGAS	AVGAS	AVGAS
93-F-539	AVGAS	AVGAS	AVGAS
93-L-100	DF-2	DF-2	DF-2
AL-20221-F	DF-2	DF-2	DF-2
AL-19915-F	DF-2	DF-2	DF-2
93-F-152	JP-4	JP-4	GROUP 4[2]
DEJESS	JP-4	JP-4	GROUP 4
93-F-347	JP-4	JP-4	GROUP 4
93-F-412	JP-4	JP-4	GROUP 4
93-F-402	JP-4	JP-4	GROUP 4
93-F-233	JP-4	JP-4	GROUP 4
93-F-586	JP-4	JP-4	GROUP 4
93-F-624	JP-4	JP-4	GROUP 4

[2] GROUP 4 consists of JP-4 and MOGAS

TABLE 20: RESULT OF CLASSIFICATION ANALYSIS USING 12 & 60 MIN DATA (continued).

SAMPLE#	FUEL TYPE	Classification of samples using the 60 min data analysis	Classification of samples using the 12 min data analysis
93-F-625	JP-4	JP-4	GROUP 4
93-F-640	JP-4	JP-4	GROUP 4
93-F-591	JP-4	JP-4	GROUP 4
93-F-653	JP-4	JP-4	GROUP 4
93-F-326	MOGAS	MOGAS	GROUP 4
93-F-307	MOGAS	MOGAS	GROUP 4
93-F-339	MOGAS	MOGAS	GROUP 4
93-F-306	MOGAS	MOGAS	GROUP 4
93-F-464	MOGAS	MOGAS	GROUP 4
93-F-638	MOGAS	MOGAS	GROUP 4
93-F-449	MOGAS	MOGAS	GROUP 4

APPENDIX C

Classification Prediction of Removed Samples

Table 21: Classification of Removed Samples Using 12 & 60 min data

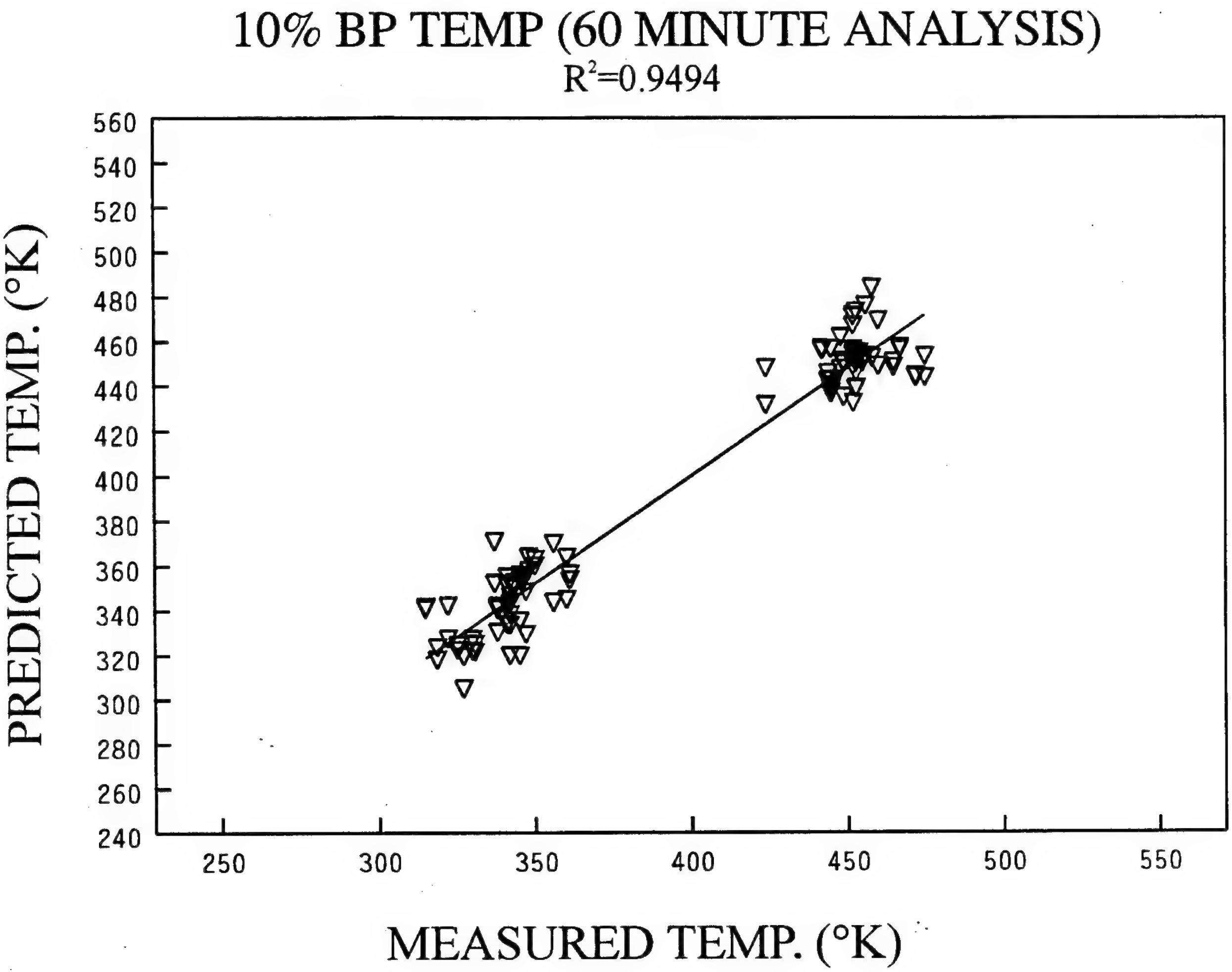
SAMPLE #	FUEL TYPE	Classification of samples using the 60 min data analysis	Classification of samples using the 12 min data analysis
92-POSF-2928	JET A	GROUP 1[3]	GROUP 1
93-F-444	JET A	GROUP 1	GROUP 1
93-F-665	JET A	GROUP 1	GROUP 1
93-F-280	JET A	GROUP 1	GROUP 1
92-POSF-2934	JP-8	GROUP 1	GROUP 1
AL-20335-F	JP-8	GROUP 1	GROUP 1
93-F-311	JP-5	GROUP 1	GROUP 1
93-F-310	JP-5	GROUP 1	GROUP 1
93-F-289	AVGAS	AVGAS	AVGAS
93-F-290	AVGAS	AVGAS	AVGAS
93-F-201	AVGAS	AVGAS	AVGAS
93-F-640	JP-4	JP-4	GROUP 4[4]
DEJESS	JP-4	JP-4	GROUP 4
93-F-402	JP-4	JP-4	GROUP 4
93-F-307	MOGAS	MOGAS	GROUP 4
93-F-326	MOGAS	MOGAS	GROUP 4
AL-20221-F	DF-2	DF-2	DF-2

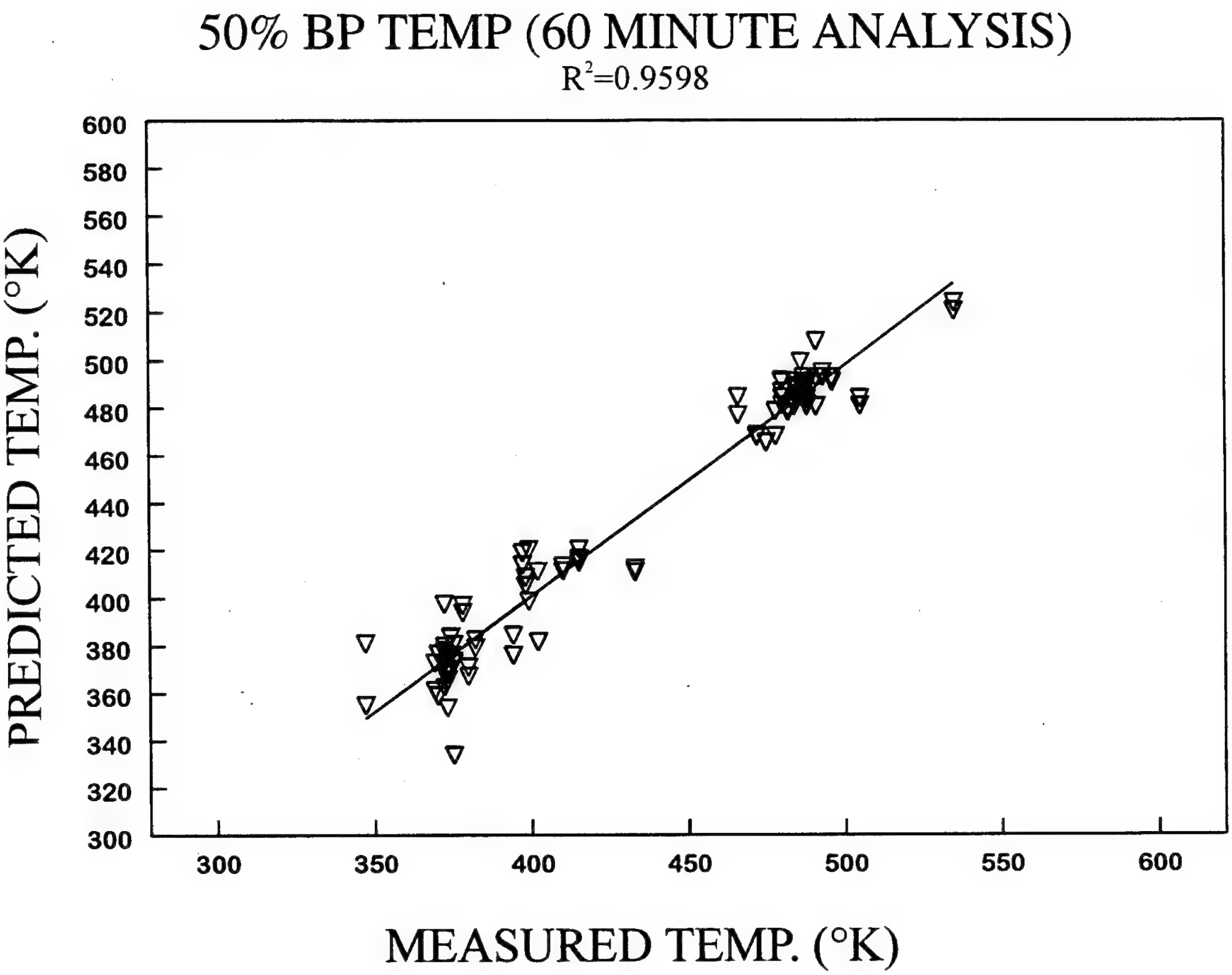
[3] GROUP 1 consists of JP-5, JP-8, JET A, and JET A-1 samples.

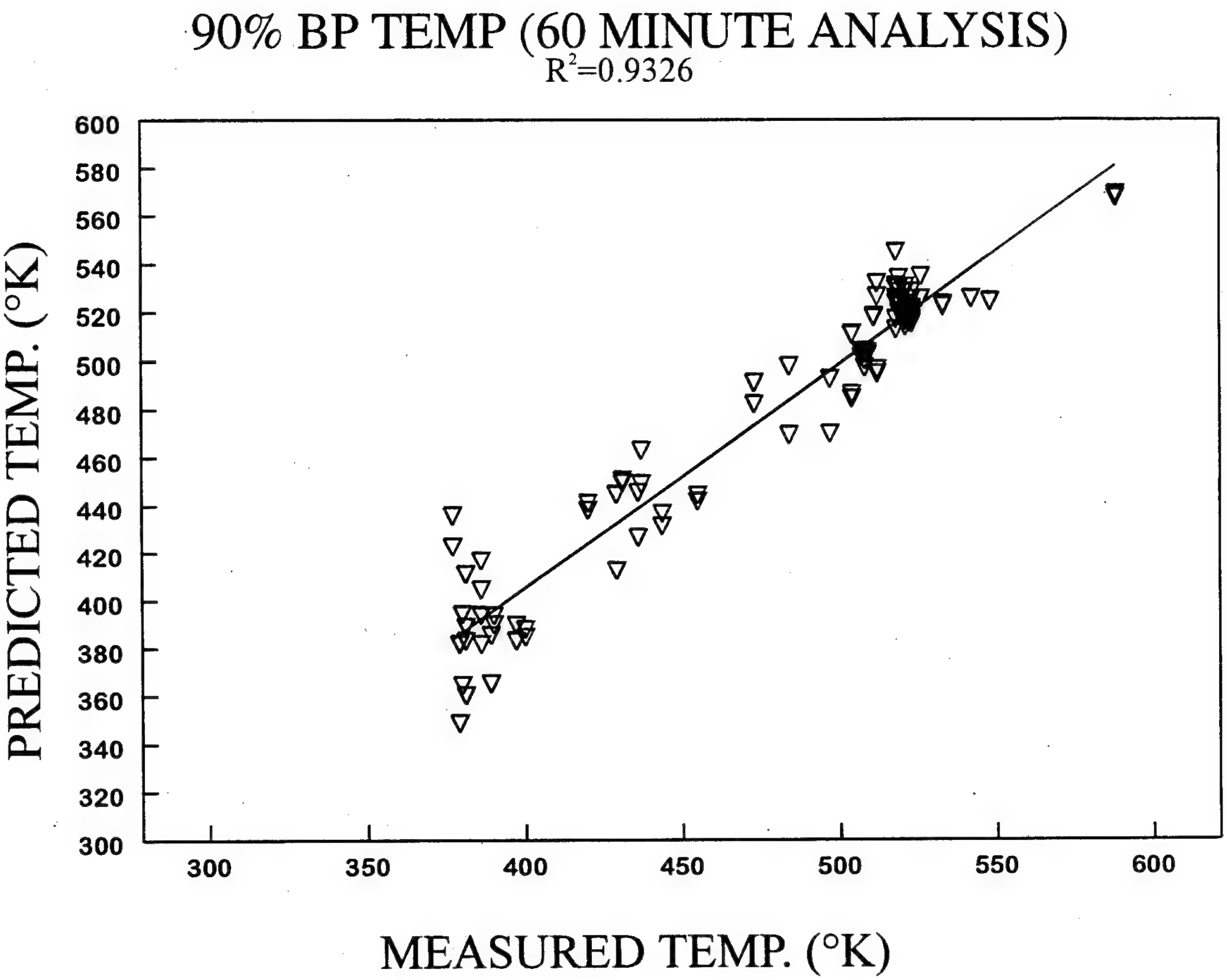
[4] GROUP 4 consists of JP-4 and MOGAS samples.

APPENDIX D

Plots of Measured Versus Predicted Parameters

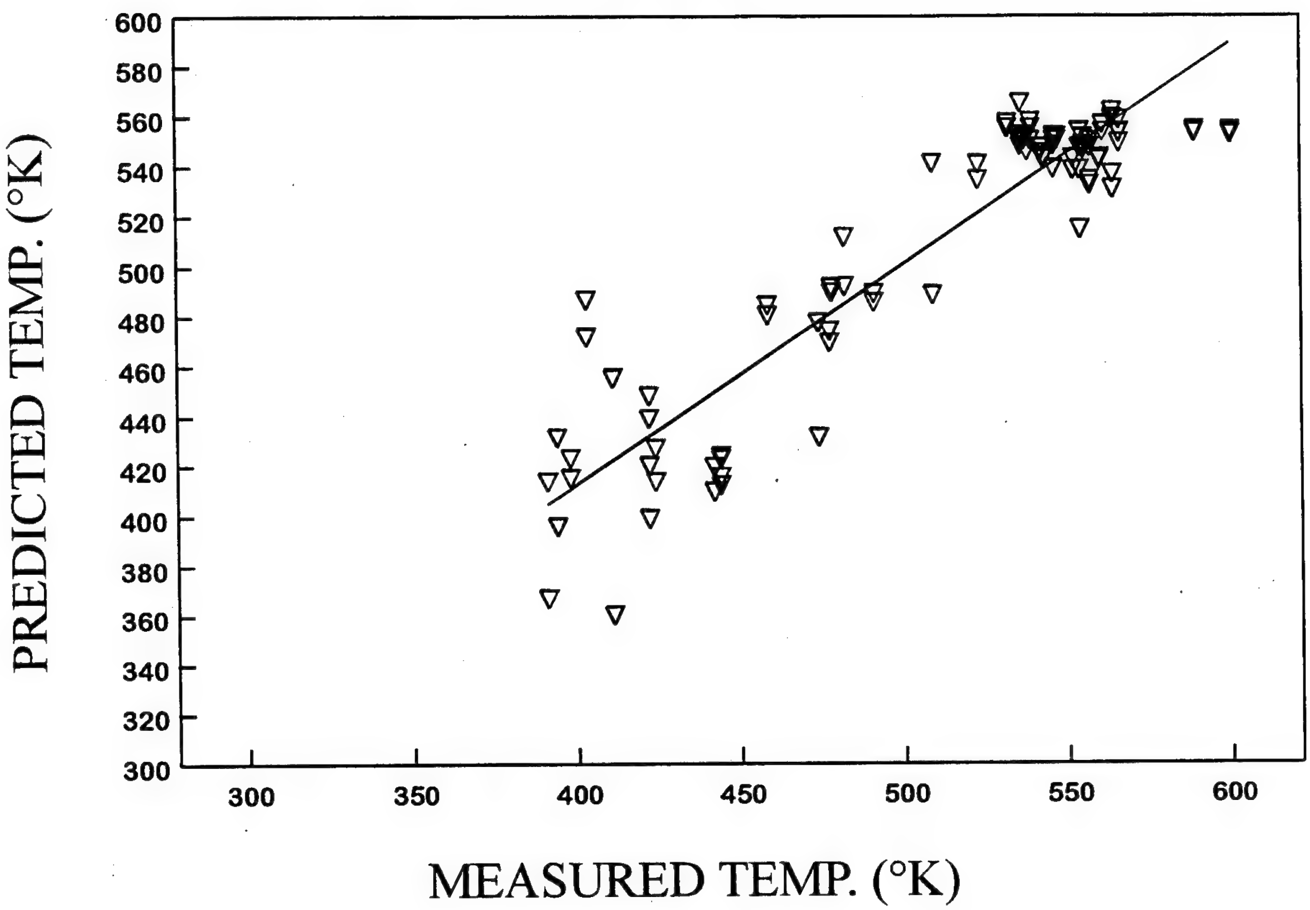

10% BP TEMP (60 MINUTE ANALYSIS)
R²=0.9494
PREDICTED TEMP. (°K)
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
250
300
350
400
450
500
550
MEASURED TEMP. (°K)

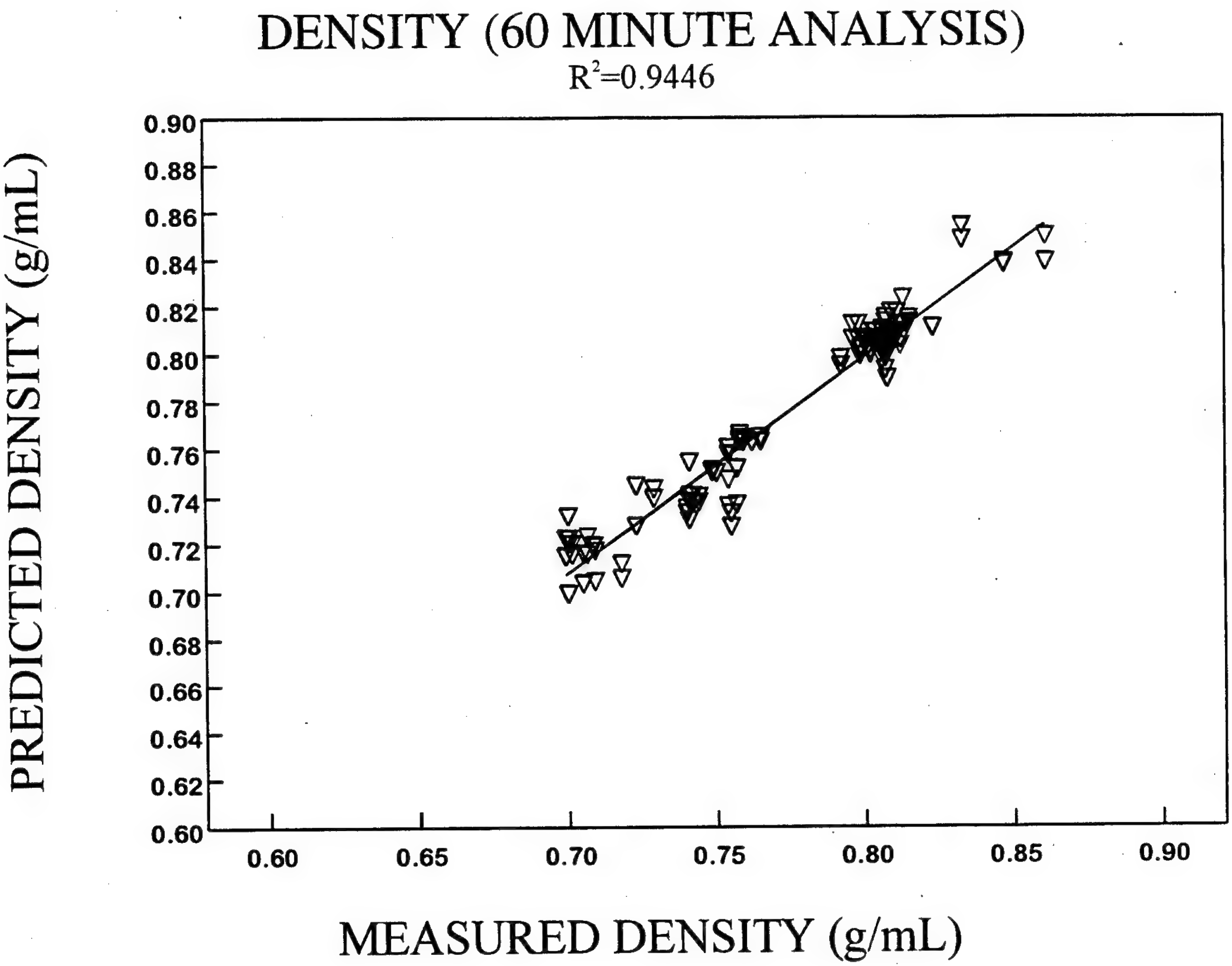

50% BP TEMP (60 MINUTE ANALYSIS)
R^2=0.9598
PREDICTED TEMP. (°K)
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
300
350
400
450
500
550
600
MEASURED TEMP. (°K)


90% BP TEMP (60 MINUTE ANALYSIS)
R²=0.9326
PREDICTED TEMP. (°K)
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
300
350
400
450
500
550
600
MEASURED TEMP. (°K)

FINAL BP TEMP (60 MINUTE ANALYSIS)

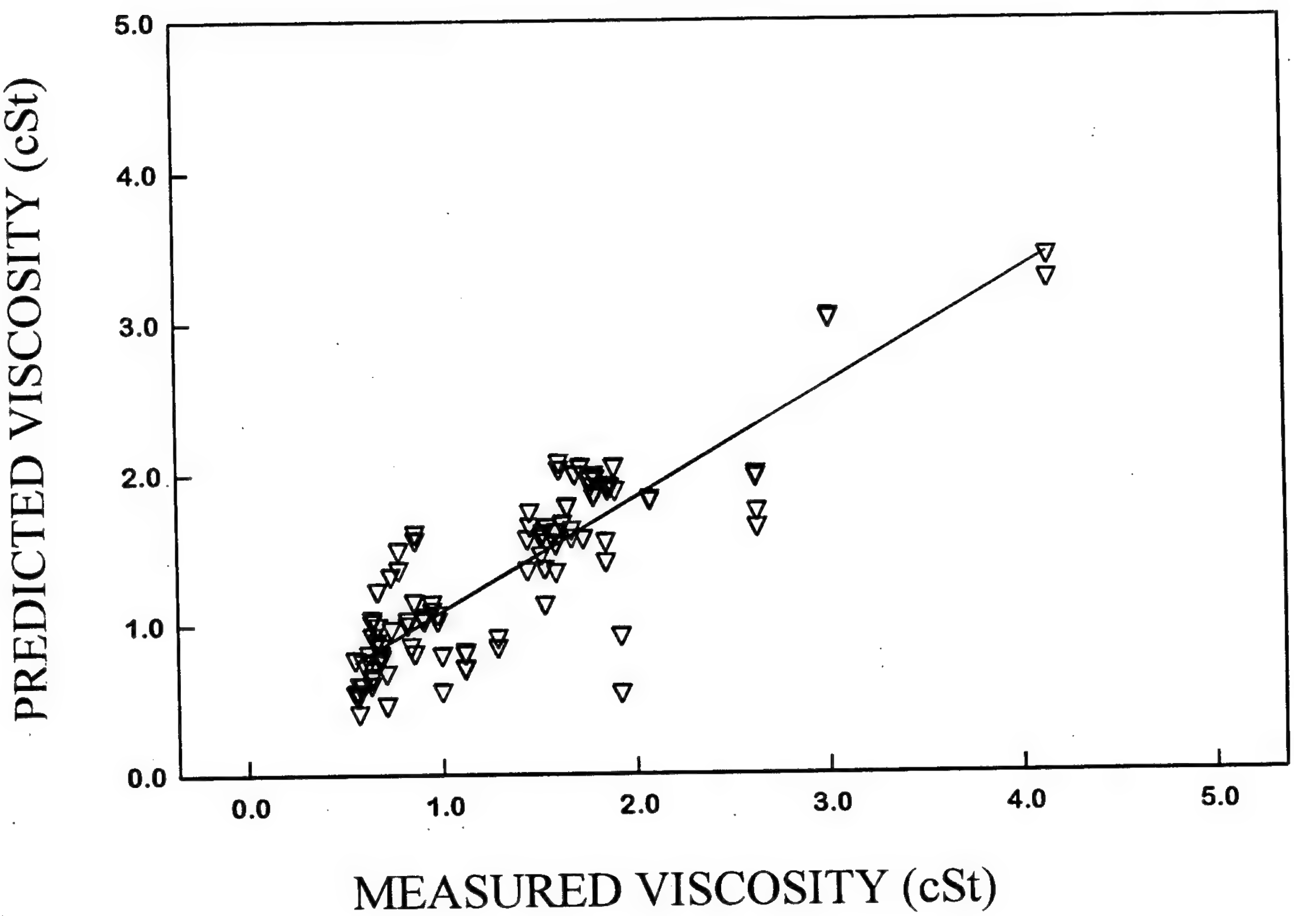
R^2=0.8586




DENSITY (60 MINUTE ANALYSIS)
R^2=0.9446
PREDICTED DENSITY (g/mL)
MEASURED DENSITY (g/mL)
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
0.60
0.65
0.70
0.75
0.80
0.85
0.90

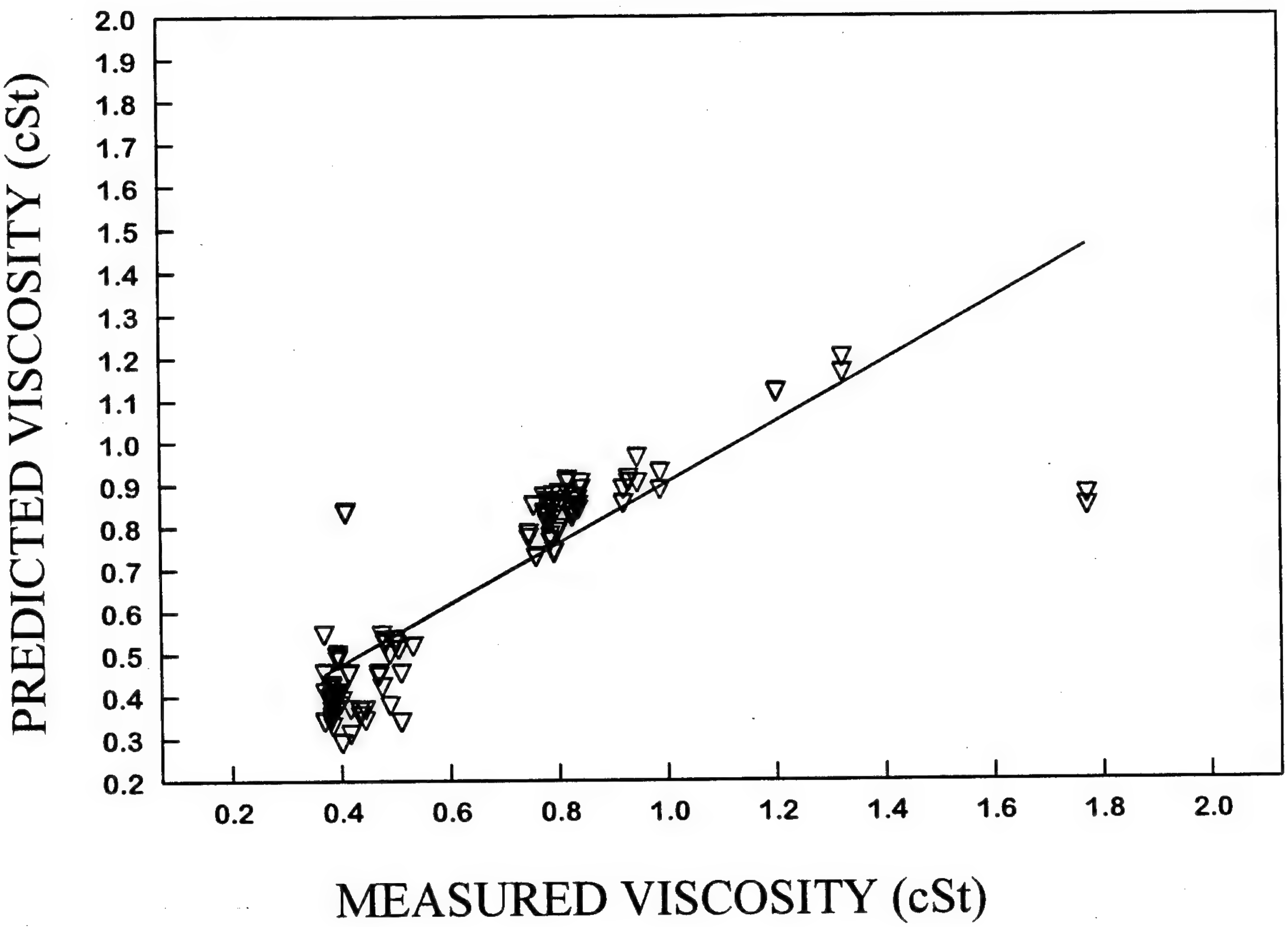
VISCOSITY @ 40°C (60 MINUTE ANALYSIS)

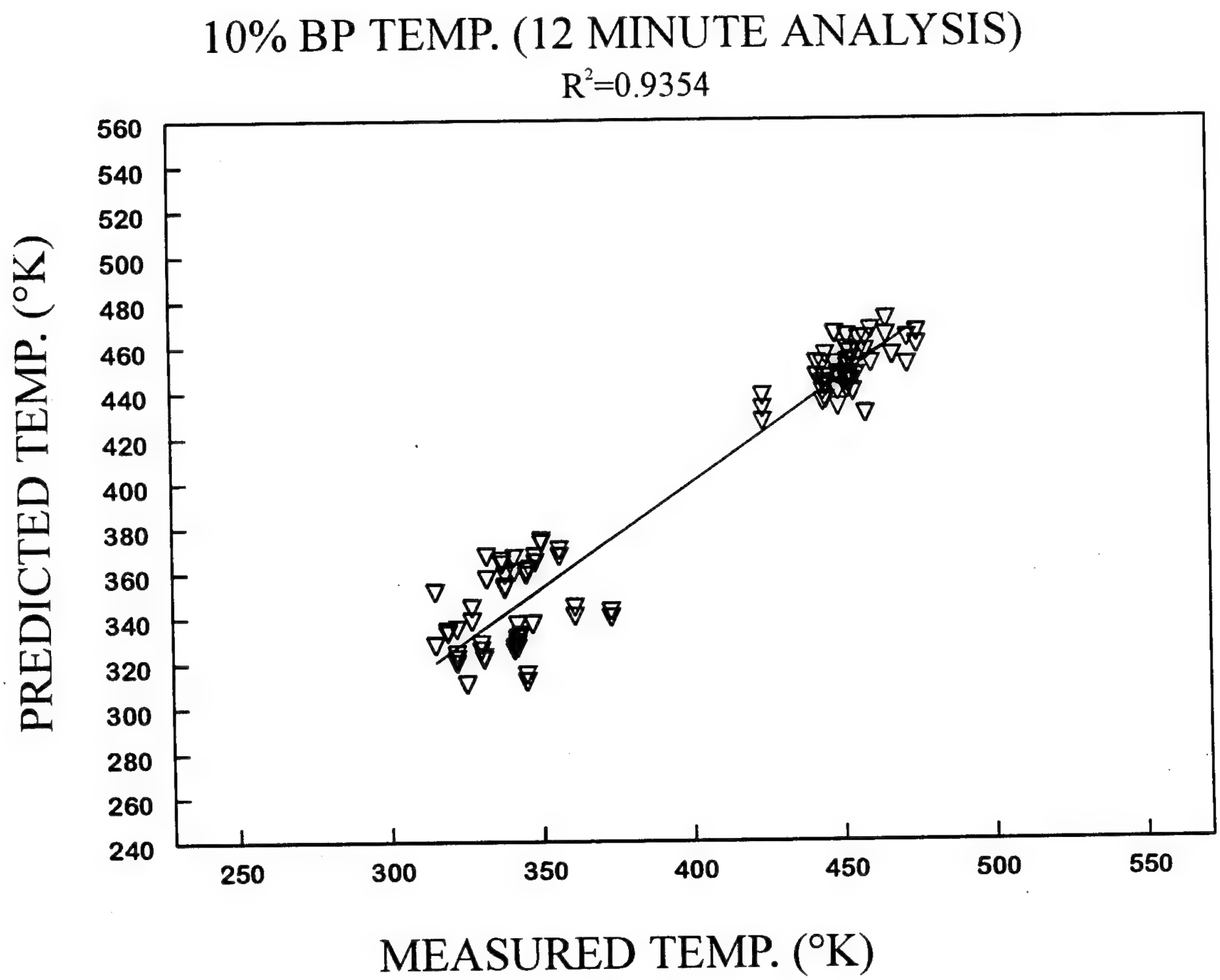
R^2=0.7507



VISCOSITY @ 100°C (60 MINUTE ANALYSIS)

R^2=0.7163

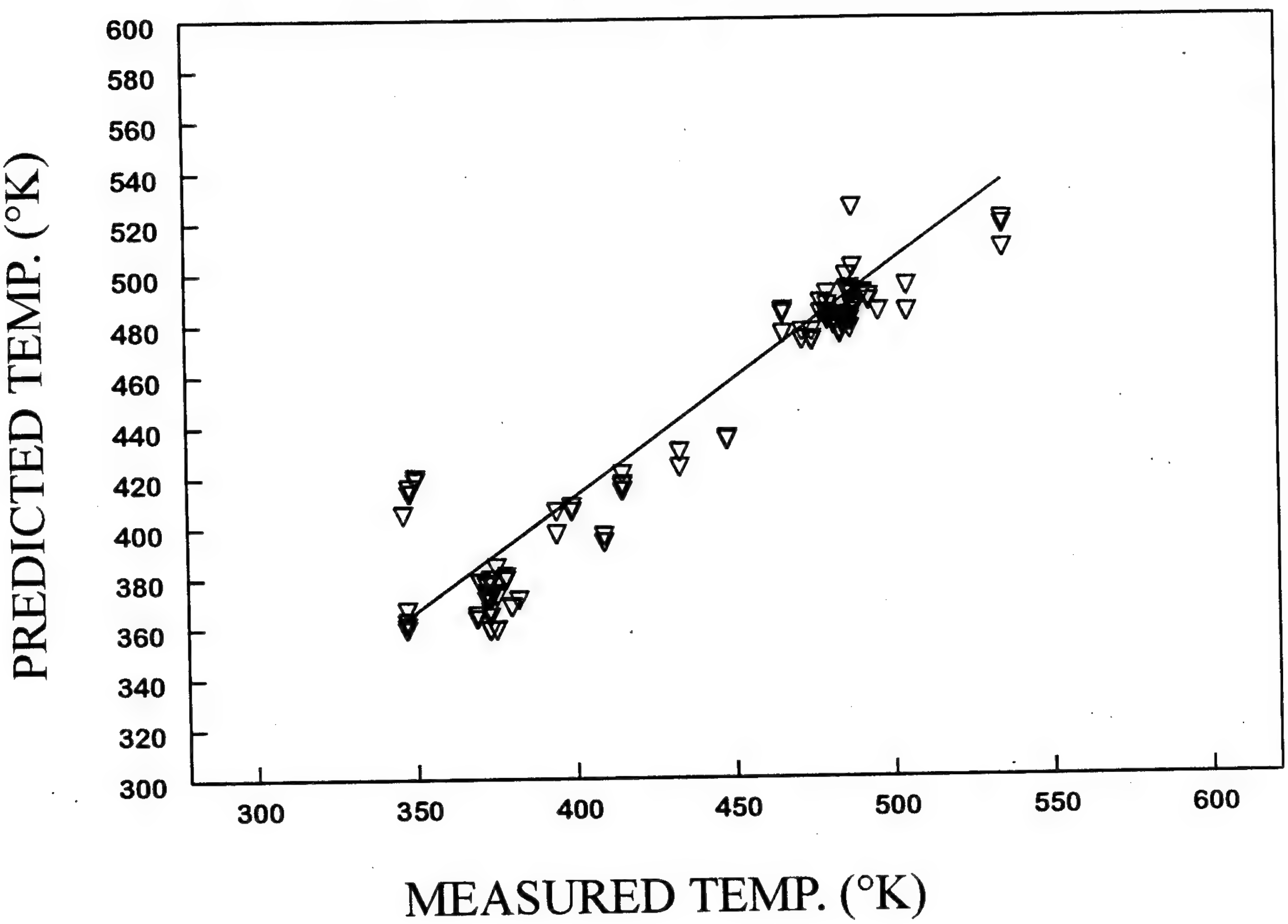




10% BP TEMP. (12 MINUTE ANALYSIS)
R²=0.9354
PREDICTED TEMP. (°K)
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
250
300
350
400
450
500
550
MEASURED TEMP. (°K)

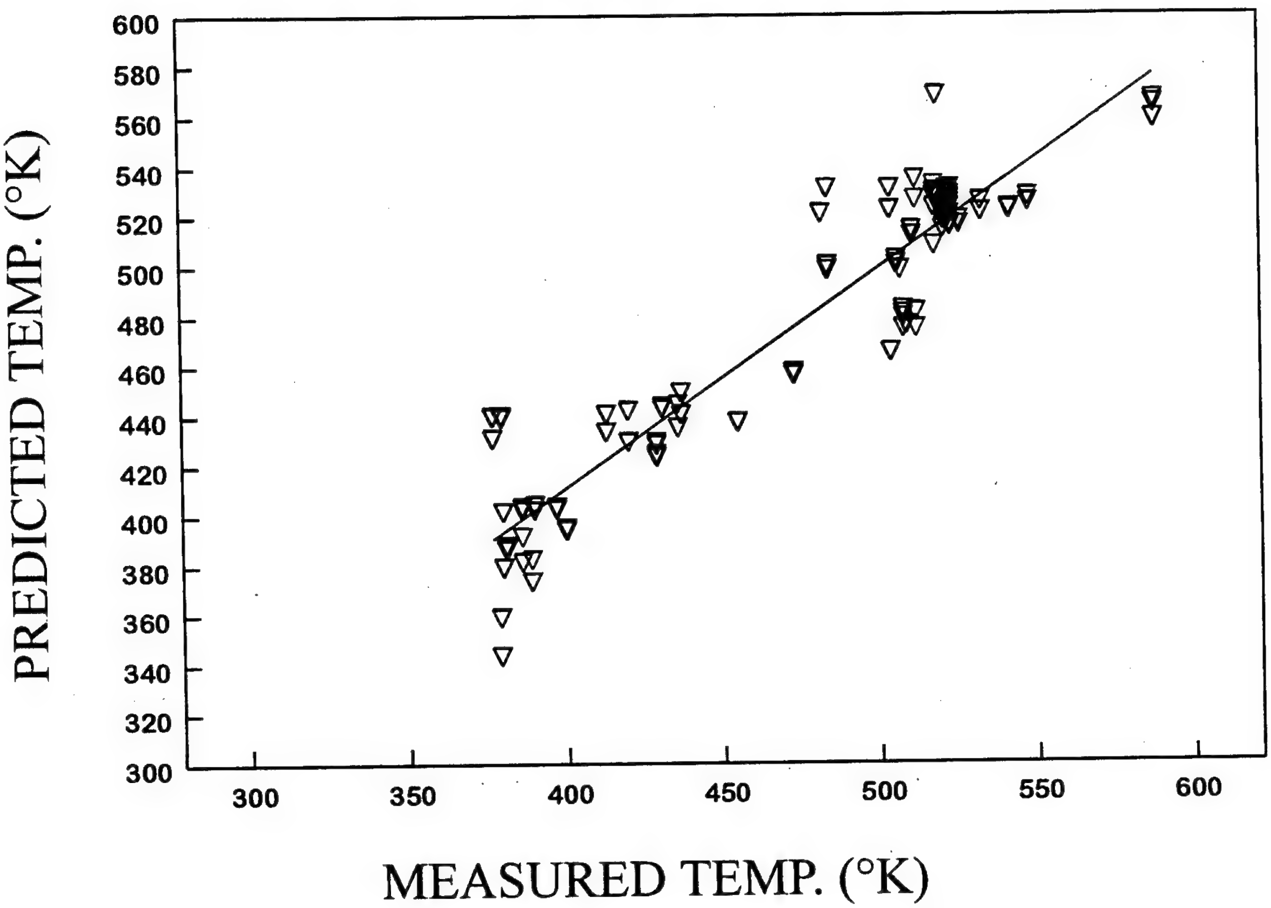
50% BP TEMP. (12 MINUTE ANALYSIS)

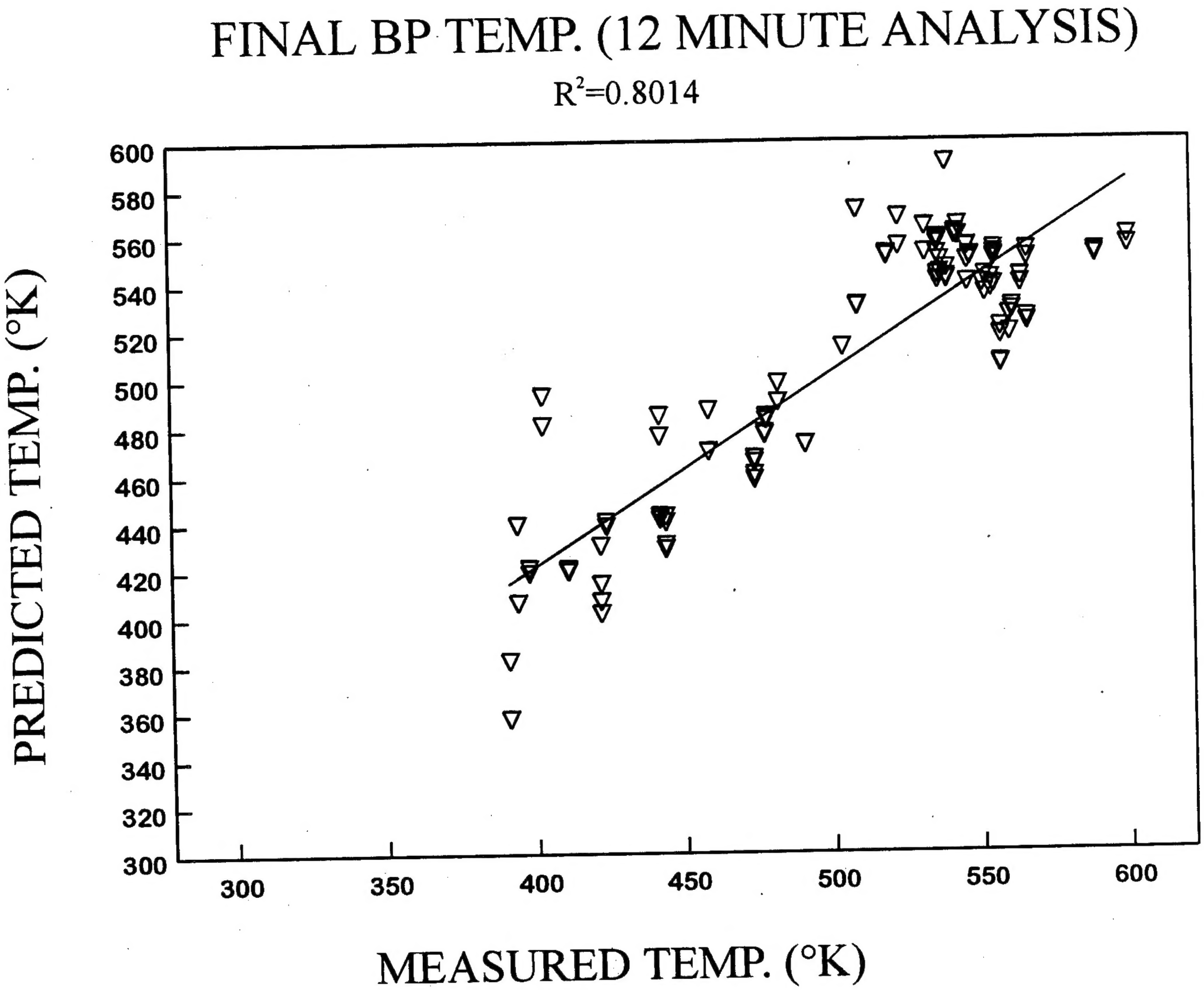
R^2=0.9143



90% BP TEMP. (12 MINUTE ANALYSIS)

R^2=0.8827




FINAL BP TEMP. (12 MINUTE ANALYSIS)
R^2=0.8014
PREDICTED TEMP. (°K)
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
300
350
400
450
500
550
600
MEASURED TEMP. (°K)

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1 ATTN AMXRO EN(D MANN)
RSCH TRIANGLE PK
NC 27709-2211

CDR ARMY NRDEC
1 ATTN SATNC US (J SIEGEL)
1 ATTN SATNC UE
NATICK MA 01760-5018

CDR ARMY CRDEC
1 ATTN SMCCR RS
APG MD 21010-5423

CDR APC
1 ATTN SATPC L
1 ATTN SATPC QE(BLDG 85 3)
NEW CUMBERLAND
PA 17070-5005

1 PETROL TEST FAC WEST
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DDRW
P O BOX 96001
STOCKTON, CA 95296-0960

CDR ARMY TECOM
1 ATTN AMSTE TC D
1 ATTN AMSTE EQ
APG MD 21005-5006

PROJ MGR PETROL WATER LOG
1 ATTN AMCPM PWL
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR ARMY BIOMED RSCH DEV LAB
1 ATTN SGRD UBZ A
FT DETRICK MD 21702-5010

CDR TRADOC
1 ATTN ATCD SL 5
INGALLS RD BLDG 163
FT MONROE VA 23651-5194

CDR ARMY QM SCHOOL
1 ATTN ATSM PWD
FT LEE VA 23001-5000

ARMY COMBINED ARMS SPT CMD
1 ATTN ATCL CD
1 ATTN ATCL MS
1 ATTN ATCL MES
FT LEE VA 23801-6000

CDR ARMY CACDA
1 ATTN ATZL CD
FT LEAVENWORTH KA 66027-5300

CDR ARMY SAFETY CTR
1 ATTN CSSC PMG
1 ATTN CSSC SPS
FT RUCKER AL 36362-5363

CDR ARMY YPG
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2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

1 PROG MGR GROUND WEAPONS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

1 PROG MGR ENGR SYS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR MARINE CORPS SYS CMD
1 ATTN SSE
2030 BARNETT AVE STE 315
QUANTICO VA 22134-5010

DEPARTMENT OF DEFENSE

12 DEFENSE TECH INFO CTR
8725 JOHN J KINGMAN RD
SUITE 0944
FT BELVOIR VA 22060-6218

ODUSD
1 ATTN (L) MRM
PETROLEUM STAFF ANALYST
PENTAGON
WASHINGTON DC 20301-8000

ODUSD
1 ATTN (ES) CI
400 ARMY NAVY DR
STE 206
ARLINGTON VA 22202

HQ USEUCOM
1 ATTN ECJU L1J
UNIT 30400 BOX 1000
APO AE 09128-4209

US CINCPAC
1 ATTN J422 BOX 64020
CAMP H M SMITH
HI 96861-4020

CDR DEFENSE FUEL SUPPLY CTR
1 ATTN DFSC I
8725 JOHN J KINGMAN RD
SUITE 2941
FT BELVOIR VA 22060-6222

DIR ADV RSCH PROG AGENCY
1 ATTN ARPA/ASTO
3701 N FAIRFAX DR
ARLINGTON VA 22203-1714

DEPARTMENT OF AIR FORCE

HQ USAF/LGSF
1 ATTN FUELS POLICY
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

AIR FORCE WRIGHT LAB
1 ATTN WL/POS
1 ATTN WL/POSF
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

1 SA ALC/SFT
1014 BILLY MITCHELL BLVD STE 1
KELLY AFB TX 78241-5603

OTHER FEDERAL AGENCIES

NASA
1 LEWIS RESEARCH CENTER
CLEVELAND OH 44135

NIPER
1 PO BOX 2128
BARTLESVILLE OK 74005

DOE
1 CE 151 (MR RUSSEL)
1000 INDEPENDENCE AVE SW
WASHINGTON DC 20585

EPA
1 AIR POLLUTION CONTROL
2565 PLYMOUTH RD
ANN ARBOR MI 48105